Introduction

Among all cereal species, maize is a superior cereal crop regarding the total production globally and grain yield capacity per given area. Over 150 million hectares of land are currently used for maize production. Maize is the most important cereal feed for livestock and is a critical staple food for several hundred million people living in Asia, Africa and Latin America. Maize represents the main source of calories and minerals for many rural populations in a number of developing countries. Maize is, however, very poor in concentrations of protein and micronutrients, especially zinc. Therefore, in countries where maize consumption is very high, the incidence of micronutrient malnutrition is also very high, particularly zinc deficiency. The enrichment of maize with high levels of zinc is a growing global challenge in order to contribute to the well-being of human populations who rely on maize for their nourishment. Although maize has a huge grain yield capacity on a given area, its yield can be significantly affected by adverse soil and climatic conditions, such as drought stress and mineral nutrient deficiencies. Like durum wheat and rice, maize is also highly susceptible to soil zinc deficiency (Figure 1).

Maize:

- Over 150 million hectares of land are currently used for production
- More than 100 countries produce maize
- Critical staple food in Asia, Africa, and Latin America
- highly susceptible to soil zinc deficiency

Figure 1: Growth of maize plants with Zn (50 kg $ZnSO_4.7H_2O$ per ha) and without Zn. Research farm of Bahri Dagdas International Agricultural Institute in Konya, Central Anatolia

Deficiency Symptoms and Leaf Concentrations of Zinc

The most common symptoms of zinc deficiency in maize include the development of whitish or yellowish stripes parallel to the midrib on the young leaves and stunting appearances with shortened internodes. Necrotic spots and reddish color may develop on leaves at the advanced stage of zinc deficiency (Figure 2). The zinc-deficient leaves presented in Figure 2 contain eight to 10 ppm zinc in dry weight. In most cases, leaf zinc concentrations below 15 ppm are classified as zinc-deficient.

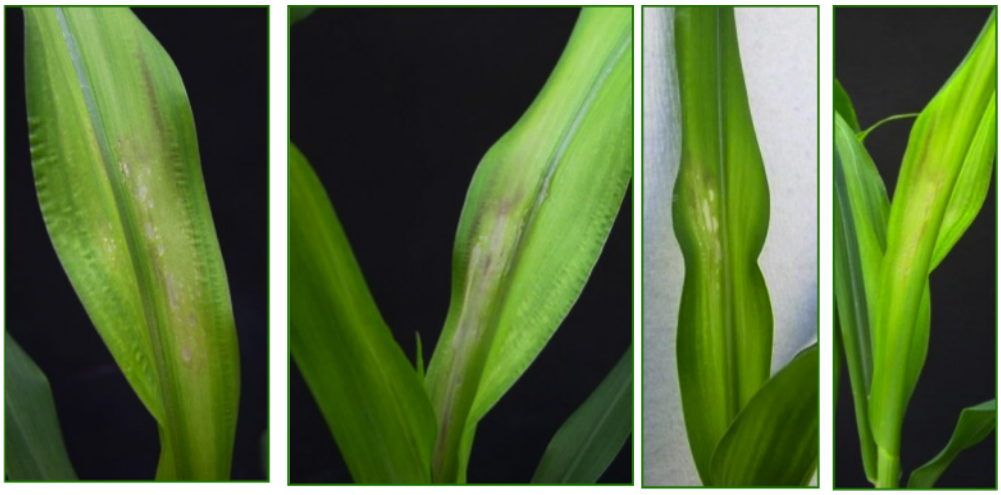

Figure 2: Development of symptoms of zinc deficiency in young leaves on a maize plant, including necrotic spots, reddish discoloration, and chlorotic striping.

Maize yield might also be reduced due to zinc deficiency without occurrence of the described zinc deficiency symptoms. In maize plants, like many crops, hidden zinc deficiency has been well documented. In some cases, this hidden zinc deficiency results in reductions in yield of up to 40% without the appearance of distinct leaf symptoms. It is, therefore, important to include zinc in the commonly applied NPK fertilizers in order to ensure that maize will not have zinc deficiency stress. It is also important to monitor and measure regularly the nutritional status of plants and soils with zinc.

Soil Tests

Determination of diethylene triamine pentaacetic acid (DTPA) extractable zinc is the most widely used method for measuring the zinc status of soils. In the extensive calibration tests conducted in diverse soils in the U.S. and India by using maize crops, it was found that DTPA-Zn concentration in soils correlated very well with the root uptake of zinc. Most commonly reported critical concentrations for the DTPA-Zn range between 0.5 to 0.7 ppm. Maize plants growing on soils containing less than 0.5 ppm DTPA-extractable zinc often respond to zinc fertilization and show increases in grain yield. In Central Anatolia (Turkey), where the soils have very severe zinc deficiency (DTPA-Zn: 0.1 ppm), it is impossible to have a proper plant growth and grain yield without soil zinc application (see Figure 1).

Correction of Zinc Deficiency

Zinc sulphate and zinc oxide are the most commonly applied zinc fertilizers. There are several reports in literature showing that grain yield of maize can be increased up to 50% by applying 10 kg zinc per hectare either in form of $ZnSO_4$ or ZnO. As indicated above, balanced fertilization programs must include zinc because various field trials conducted in many countries, especially in India and China, showed significant yield increases when zinc was included as part of a balanced fertility program. Due to extensive depletion of plant-available zinc in soils by cultivating high-yielding maize hybrids, application of zinc fertilizers or using zinc-fortified NPK fertilizers is an important practice for maize growers to maintain high yields and profitability.

Phosphorus-induced zinc deficiency has been extensively reported in literature. It is important to take account of

zinc fertilization in the fertilizer programs when phosphorus fertilizers are applied regularly and at high amounts. High rates of phosphorus fertilization may significantly depress mycorrhizal activity of roots. (Mycorrhizae is a root-associated fungus that significantly contributes to root zinc uptake from soils.)

Effects of Zinc on Corn Production in China

IZA's Zinc Nutrient Initiative sponsored a total of 64 field trials were conducted at farm fields in China in 2011 and 2012. In most fields, soil test zinc levels were from 0.3 to 1.3 mg Zn/kg (DTPA extractable zinc). Results showed that application of 15 kg and 30 kg $ZnSO_4.H_2O$/ha increased corn yields by 6.3% and 8.5%, respectively, which brought high economic returns (value increased:Zn cost ratio) to farmers with the average 10.5 for 10 kg $ZnSO_4.H_2O$/ha and 7.5 for 20 kg $ZnSO_4.H_2O$/ha. Zinc fertilizer increased corn yield by an average of 7.8% for soil application and 5.7% for foliar spray. Zinc application by soil plus foliar spray and fertigation at 15 kg $ZnSO_4.H_2O$/ha rate increased corn yield by 8.5 and 10.9%. Zinc fertilizer increased Zn concentration in corn grain by average of 20% and 35% for 15 and 30 kg ZnSO4.H2O/ha, respectively. Foliar application, especially soil plus foliar application had better effects in improving grain Zn concentrations. Zinc application also helped increasing corn grain nitrogen content by 3-6 kg/ha, improving nitrogen efficiency by 1.7 to 3.4%.

Conclusion

Generally, soil zinc applications are more effective in increasing grain yield than the foliar application. However, foliar application of zinc fertilizers could be very helpful in improving grain zinc concentration and thus contributing to human nutrition. Heavy and continuous consumption of maize-based diets is generally associated with zinc deficiency in human populations. Therefore, soil and/or foliar applications of zinc fertilizers should be considered not only for increasing yield but also for improving nutritional value of grain for human populations.